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Artificial Intelligence and Waveform Diversity

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Abstract - *Future US Air Force sensor systems must be able to adapt to changing environments in real time. A capabilities-based modeling approach offers a new method for building the next generation weapon system. To accommodate this model based approach, the Department of Defense (DoD) is promoting the use of waveform diversity for active radar systems. Building a weapon system including one or more systems with waveform diversity will require the use of artificial intelligence (AI) tools and techniques. This paper provides a model of how an aircraft sensor system can be retrofitted to accommodate radars employing waveform diversity without causing fratricide.*

1. Introduction

The Quadrennial Defense Review 9/30/01 states that: "The new defense strategy is built around the concept of shifting to a "capabilities-based" approach to defense." Where: "A capabilities-based model - one that focuses more on how an adversary might fight than who the adversary might be and where a war might occur - broadens the strategic perspective." The DoD has always had a capabilities-based philosophy in developing weapon systems. They assess their capabilities, predict what the enemy's capabilities would be and develop new or improved weapon systems that would provide the DoD with military superiority. However, today's adversaries are difficult to predict. From [1]

"...the subject matter for most military analysts is far more fluid than during the cold war, rendering standard databases and analytical models for explaining behavior obsolete. Indications and Warning, the analysis which warns of impending attack on the United States or its vital interests, depends on the ability to predict enemy activity, based on enemy plans, doctrine, and observed exercises and training. Many of today's potential adversaries offer little in the way of traditionally observable activity."

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The enemy is not one nation, with borders, that fights like past adversaries. In order to defeat enemies we must be able to encounter them anywhere with battle lines that are difficult to draw on the Earth or in cyberspace. We must be adaptable, quick, innovative, and intelligent in the use of all weapons and information. The time to assess the enemy and plan for the next battle is measured in hours and days not years. We can make some modifications to weapon systems and how they are deployed to meet today's demands, e.g. unmanned air vehicles. However, other systems will take longer to modify, such as, radar and communications systems. Future US Air Force sensor systems must be able to adapt to changing environments in real-time if we are going to defeat a distributed and highly unpredictable enemy.

This paper proposes an approach for the building of our next generation radar sensor systems using waveform diversity. The next section provides a background. The third section describes an intelligent sensor system architecture. The fourth section discusses some of the major elements of waveform diversity. The fifth section presents information related to electromagnetic fratricide, a concern when employing waveform diversity on a platform of sensors. The sixth section presents some thoughts about an intelligent platform network to manage the goals of a platform or system of sensors. The last section provides a summary and future work.

2. Background

Current signal processing systems are optimized for their processing requirements whether the systems are mounted on an aircraft, a missile, a spacecraft, or at a ground based site. The algorithms are "hardwired" into the computer's architecture in order to meet the real-time requirements demanded by the sensor's operating parameters, e.g. scans per second and number of sensor elements. This "static" approach to building radar systems is being investigated by the radar research and development community and is likely to evolve, in the

near future, to be more dynamic. As a result, different algorithms and/or their parameters will be modified by the radar's software as the environment or directives change. For instance, if a radar is being jammed by a transmitter from a particular direction, then that radar could place a null in its antenna pattern to reduce the affect of the jammer. This and many more sophisticated algorithms have been studied and numerous research papers have been written.

Some of the most progressive work in employing artificial intelligence (AI) techniques has been pursued by the US Air Force Research Laboratory's Sensors Directorate. Their original efforts have been focused on the constant false alarm rate (CFAR) portion of a radar's signal processing chain. Work was performed [1] to demonstrate that if the cell under test is near the boundary of two different clutter regions, then blindly applying a CFAR algorithm (like cell averaging) will not perform as well as choosing only those cells with the same type of clutter as the test cell. This approach provides a better probability of detection and a lower false alarm rate. However, to apply this approach on an airborne radar, whose main clutter is from the Earth, requires that the registration of each cell on the Earth be known and the type of clutter be categorized. Therefore, the algorithm must be dynamic in order to perform this registration for each of the radar's coherent processing intervals (CPIs). Laboratory experiments with radar data have shown good results especially when a radar is illuminating heterogeneous clutter boundaries such as land sea interfaces.

This type of work was extended beyond the detection stage to the entire radar processing chain under a US Air Force (USAF) effort dealing with knowledge based space-time adaptive processing (KBSTAP) [2,3]. This effort demonstrated the benefits of using outside data sources to affect the filtering, detection and tracking stages of a surveillance radar. Data from a side looking airborne radar system was used in demonstrating the performance enhancements in comparison to a conventional radar. The measurements were obtained from the multi-channel airborne radar measurement (MCARM) program [4] funded by the USAF. Another program showed the benefits of using map data obtained from the US Geological Survey (USGS) to improve the performance of STAP on an airborne radar (MCARM) by selecting training data based upon terrain information rather than blindly choosing the range rings surrounding the test range ring. This effort, KBMapSTAP [5,6], along with numerous researchers have laid the ground work for a new DARPA program. The Knowledge-Aided Sensor Signal Processing Expert Reasoning (KASSPER) program is investigating the use of outside data sources to dynamically change a radar's signal processing chain in order to enhance performance.

Using current technology, we can build new radar systems that can dynamically change its processing given information from other sensors, outside sources, weather data, etc. The computing clock rates for computers have been doubling approximately every 18 months. Today's commercial off-the-shelf computers have clock rates exceeding 3 GHz. The computing power is available to insert sophisticated "rules/logic" within radar signal and data processing.

We need a new approach for building our next generation systems not only for a single radar system but also for a platform of sensors. We need to envision our sensors not as stand-alone systems but a system of sensors, whether they are mounted on one platform or multiple platforms. Waveform diversity is that technology that will allow one or more sensors to automatically change its operating parameters, e.g. frequency, gain pattern, pulse repetition frequency (PRF), etc. This will allow a system of sensors to adapt operation to meet the stressing and changing environments that military systems must face and therefore meet the intent of a capabilities-based approach.

3. An Intelligent Sensor System

If an airborne radar is going to share and receive information from multiple sources then it must be able to communicate and understand the information. A solution for the exchange of information between heterogeneous sensors is for each sensor to publish information based upon an agreed and understood format (i.e. an ontology). The reader is referred to a companion paper in these proceedings [9] which provides more explanation of how these different sensors can communicate.

Sharing information between sensors on the same platform and between platforms is required, especially if one or more sensors are adaptively changing waveform parameters to meet the demands of a changing environment. Figure 1 depicts a hypothesized intelligent sensor system. Each of the sensors has its own signal and data processing capability. In addition to this capability, we have added an intelligent processor to manage sensor fusion, communication and control. The goal is to build this processor so that it can interface with any sensor and communicate with the other sensors using ontological descriptions via the intelligent platform network. The intelligent network will coordinate the communications between the sensors onboard and offboard. It will determine if there is an EM interference (EMI) potential when a sensor varies their antenna's main beam pointing vector, or changes its PRF and may thereby cause interference to a receiving sensor. Rather than have each sensor on a

platform operate as an independent system, we need to design our platform as a system of sensors with individual and global goals managed by an intelligent platform network. This is one of the major issues we are pursuing under our sensors as robots initiative. This initiative is addressing attended and un-attended sensor platforms.

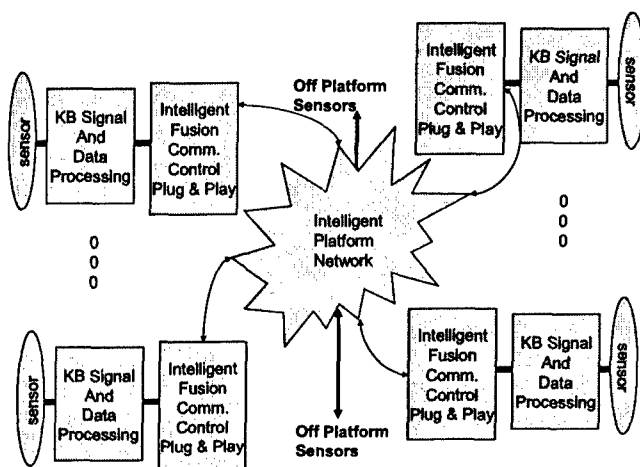


Figure 1 - An Intelligent Sensor System

4. Waveform Diversity

One of the major objectives of waveform diversity is to control the emission spectra of a radar to increase its performance and to perform multiple functions such as imaging and tracking of targets. However, if we place one or more radar and/or communications systems on an aircraft platform, we need to consider how to retrofit an aircraft and how to control the diversity of these systems to avoid EM fratricide. The degree of communications implicitly shown in Figure 1 does not exist today. An aircraft's communications and radar systems, for the most part, do not communicate with each other. However, a radar system may have access to data from the onboard navigation system. There are approaches we can exploit to build this system by using fiber optic or wire links onboard the platform. Radio frequency (RF) links using Bluetooth or 802.11 technologies can be exploited for linking these sensors onboard the platform. The communications issues need to be addressed for the sharing of information and for minimizing the potential of EM fratricide.

The design presented in Figure 1 has three levels of artificial intelligence (AI) algorithms for the sharing of information. The first set of algorithms is contained within the knowledge based (KB) Signal and Data Processing (KBSADP) and represents the work being performed on the KASSPER program and [2 - 8]. The

next level of AI algorithms interfaces KBSADP with the intelligent platform network.

The Intelligent Fusion Communication Control, Plug & Play (IFC2P2) software module will share information with the KBSADP module and the Intelligent Platform Network (IPN) via the ontologies discussed in [9]. This sharing will allow each sensor system to request/provide information from/to other sensor systems for their intelligent processing. The IFC2P2 could reside on a separate processor with a network connection to the IPN and a connection to KBSADP or it could reside on the KBSADP processor. For existing sensor systems, software will be created to translate data to/from their data formats to the attributes defined in the common ontology. The IFC2P2 processor may have a graphical user front end, depending upon the sensor system, for viewing requested information, controlling the KBSADP processor, and assessing the results of sensor fusion. This sharing of information is valuable for new sensor systems, that can exercise waveform diversity functions, and for older systems without waveform diversity functions.

5. Electromagnetic (EM) Fratricide

EM fratricide is that situation where we degrade the performance of our own system(s), with our own system(s), e.g. an onboard radar's energy is received by an onboard receiver and degrades its performance. This is a problem, since there are multiple sensor systems onboard a platform. Military weapon systems are engineered to prevent such phenomena between hardware located in close proximity, e.g. on an aircraft, ship, or spacecraft. The military has standards for describing how to build and test hardware for EMC, and how to test weapon system platforms for EMC, e.g. Military Standards 461, 462, and 6051 (or 464). The USAF has also developed EMC prediction tools to assess the EMC of its weapon systems. These tools were developed during the 1970s and 1980s and have been enhanced and used throughout this time. They were developed to work with the above military standards to assure proper testing of systems was performed, because most of the new systems developed then, were being deployed in space where fixing EMI problems is not feasible. Using software tools for guiding EM measurements in the 1970s was a major paradigm shift for the EMC community.

Just as we needed a change by using software tools to assess a system's EMC in the 1970s, we need to rethink again how we build complex systems that employ waveform diversity. In the 1970s we required software tools to predict where to hone our measurements, we now need to use intelligent software tools to help us determine when EMI may occur in real-time and manage the EM spectrum while having the platform increase its EM performance. This performance is related to not one

system onboard the platform but a system performance measure of the total platform, where the platform may contain communications, navigation, radar sensors, etc. The EMC tools used today assess the performance of an individual stove pipe system e.g. the increase in bit error rate of communications equipment and the decrease in probability of detection of a radar. The prediction of these performance measures are usually related to the signal to noise plus interference ratios computed for each transmitter coupled to each receiver. The tools also compute the sum or integration of all of the transmitters coupling into a receiver(s) along with a hypothesized EM spectrum, to represent the environment, and predict an integrated or total EM ratio which can be related to a receiver's performance. This method identifies the performance of each receiver but it does not alert us as to the degradation of the total weapon system's performance. In addition, each computation is performed for a fixed set of operating conditions for each transmitter and receiver of EM energy. This approach is acceptable when analyzing a weapon system with conventional equipment where each system's performance is assessed independent of all others. However, this is not acceptable for a weapon system or platform with a global performance requirement(s) or when the waveform parameters of one or more of its sensor systems are changing in real-time.

6. Intelligent Platform Network (IPN)

The issues of EM fratricide are much larger than assessing or knowing that a sensor is being degraded because of the emissions of one or more of the transmitters onboard the platform. A system level performance measure must be developed that changes both in time and space depending upon the scenario of the platform. We can model this as a time varying objective function that needs to be optimized given a finite constraint set representing the different modes each of the individual platform systems may operate within. We need a dynamic model for each of the equipments onboard the platform and its embedded EM environment. The objective function will be monitored by the IPN so that it can determine whether requests from individual sensors onboard, due to waveform diversity, can be granted given the performance goals of the platform and the state of the objective function. The requests from the individual sensors are being made either at the KBSADP or IFC2P2 levels of processing. Granting requests to either of these levels by the IPN will depend on many factors and computations that will have to be made in real-time for maintaining EMC of the platform and above all meeting the total performance of the platform.

We don't envision there is a simple solution to this problem. However, we have the basic EM coupling models available today. We need a method of representing the objective functions for system level

performance, individual equipment models require some improvements, and a method of intelligently assessing the situation and granting requests and/or suggesting alternatives when grants can't be made. An AI paradigm for managing the different sensor system requests should be studied and system level models developed and tested.

7. Summary and Future Work

Motivation for a new approach for building our next generation sensor systems was presented. A background section provided an overview of some of the military funded work that is integrating artificial intelligence technology into our sensor systems was also presented. An intelligent sensor system utilizing ontologies was described. We provided a brief description of waveform diversity and how the multiple sensors onboard a platform could intelligently communicate and share information using AI technology. A discussion of EM fratricide as one of the major issues in fielding a platform with one or more waveform diversity equipments was presented. A system level performance objective(s) was discussed for managing the EM spectrum of a waveform diversity platform. Future efforts should address further development of the intelligent sensor system. We need to investigate analytical methods for modeling the performance goals of a system of sensors. We also need to model the real-time assessment and control of the EM spectrum for minimizing EM fratricide and maximizing performance.

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